NASA TN D-323

NASA TN D-323

/N-18
381514

TECHNICAL NOTE
D-323

A FLIGHT STUDY OF A POWER-OFF LANDING TECHNIQUE APPLICABLE TO RE-ENTRY VEHICLES

By Richard S. Bray, Fred J. Drinkwater III,
and Maurice D. White

Ames Research Center
Moffett Field, Calif.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON July 1960

Y

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL NOTE D-323

A FLIGHT STUDY OF A POWER-OFF LANDING TECHNIQUE APPLICABLE TO RE-ENTRY VEHICLES

By Richard S. Bray, Fred J. Drinkwater III,
and Maurice D. White

SUMMARY

A power-off landing technique, applicable to aircraft of configurations presently being considered for manned re-entry vehicles, has been developed and flight tested at Ames Research Center. The flight tests used two configurations of an airplane for which the values of maximum lift-drag ratios were 4.0 and 2.8. Twenty-four idle-power approaches were made to an 8000-foot runway with touchdown point and airspeed accuracies of ±600 feet and ±10 knots, respectively.

The landing pattern used was designed to provide an explicitly defined flight path for the pilot and, yet, to require no external guidance other than the pilot's view from the cockpit. The initial phase of the approach pattern is a constant high-speed descent from altitude aimed at a ground reference point short of the runway threshold. At a specified altitude and speed, a constant g pull-out is made to a shallow flight path along which the airplane decelerates to the touchdown point.

Repeatability and safety are inherent because of the reduced number of variables requiring pilot judgment, and because of the fact that a missed approach is evident at speeds and altitudes suitable for safe ejection. The accuracy and repeatability of the pattern are indicated by the measured results.

The proposed pattern appears to be particularly suitable for configurations having unusual drag variations with speed in the lower speed regime, since the pilot is not required to control speed in the latter portions of the pattern.

INTRODUCTION

One of the present concepts of a manned satellite vehicle is an airplanelike configuration which is capable of normal aerodynamic flight after re-entering the atmosphere. Considerations of weight suggest that the vehicle be without means of propulsion at this stage of the flight, and considerations of re-entry dynamics indicate the advantages of a configuration having a low-aspect-ratio plan form and relatively high profile drag. Even with a moderate wing loading, such a vehicle, because of its lift and drag characteristics, presents a landing problem characterized by high sink rates and high touchdown speeds. The results of references 1 and 2 point out the problem areas of power-off landings when conventional techniques are used. High approach speeds and steep glide angles adversely affect a pilot's ability to judge the approach flight path required to precisely position the aircraft at the approach end of the runway, and to judge the correct speed and altitude for initiation of the landing flare.

The reasonable aim of any power-off landing technique proposed for re-entry vehicles is accuracy and reliability of the same order as is accepted for power-on landings of current high-performance fighter aircraft. Ideally, the technique should provide the pilot with a well-defined glide path, with no external guidance other than the pilot's view from the cockpit; yet, compatibility of the technique with likely schemes of radar guidance or automatic landing would be advantageous. A satisfactory power-off landing technique, particularly for vehicles of very low lift-drag ratios, should avoid the high sink rates near the ground, inherent in patterns which include a flare from the approach glide angle just prior to touchdown. Another requirement is that the flight path be compatible with the pilot-ejection equipment, at least to the point where a successful landing is assured.

The results of previous power-on landing-approach research conducted at the Ames Research Center (ref. 3) indicate the benefits to be gained in landing performance by the reduction of the number of variables left to pilot judgment. In order to take advantage of this principle, a technique has been developed for power-off landings which incorporates a straight-in approach to the landing point along a flight path composed of well-defined straight-line elements. The approach pattern, shown in figure 1, is comprised of three phases. Phase I represents a straight-in approach to the landing area in a steep glide at a relatively high indicated airspeed. The flight path is defined by the angle of descent (matching the vehicle lift-drag ratio at the selected airspeed) and the preselected geographical reference point, P, short of the runway, at which the aircraft is aimed. Availability of speed brakes is assumed during this portion of the pattern where their high-speed effectiveness can be used for precise speed control, thereby reducing the precision required in establishing the initial flight-path angle. Phase II, the pull-out or flare, is initiated at a predetermined altitude, h, and is performed at a constant value of normal acceleration, which is maintained until the flight path of the vehicle is aimed at the touchdown point. Phase III is the final approach along a shallow flight path, nominally 3°, to the preselected point. The speed programmed for the end of phase I depends on the deceleration characteristics of the aircraft in phases II and III. Accordingly, during phases II and III, configuration changes affecting the lift-drag ratio of the airplane, such as dive brake, flap, and gear extension, must be rigidly programmed with speed.

Once the desired flight conditions of phase I have been attained, satisfactory completion of the approach demands only that the pilot enter phase II at the desired altitude. If, however, as a result of initial error in flight-path angle or speed control the conditions at the end of phase I are not within the required bounds, there remain sufficient speed and altitude for emergency ejection.

A pattern for any given vehicle configuration can be computed using appropriate lift and drag data. As an example, computations of the approach pattern for the specific flight tests of this report will be discussed in detail.

This report discusses a technique devised by the pilots at the Ames Research Center to meet the above requirements, and presents the results of flight trials of the technique.

NOTATION

a_n normal acceleration, g units

C_L lift coefficient, $\frac{a_n(W/S)}{\text{dynamic pressure}}$

d distance from selected touchdown point, ft

h altitude, ft

$\frac{L}{D}$ lift-drag ratio

V velocity, knots

$\frac{W}{S}$ wing loading, lb/sq ft

ΔC_D drag coefficient of extended dive brake

γ flight-path angle, deg

Subscripts

I phase I

II initial point of phase II

III initial point of phase III

P phase I aiming point

FLIGHT TESTS

Test Airplane

In order to best evaluate the proposed technique, as applied to vehicles with very low lift-to-drag ratios, the test airplane was flown in the highest drag configuration commensurate with flap and landing-gear structural limits. Speed brakes were out at all times except as necessary for initial speed control; below 300 knots, the flaps were in the take-off position and below 260 knots, the landing gear was extended. As can be seen in figure 2, the maximum value of lift-drag ratio for the airplane with landing gear retracted is about 4.0. In the final landing configuration, the value is reduced to 2.8. The wing loading averaged 85 pounds per square foot during the tests.

Values of indicated airspeed, indicated altitude, and normal acceleration were recorded photographically from the pilot's instrument panel. A camera located in the side of the fuselage photographed the horizon to provide pitch attitude information. Motion pictures of the final approach and touchdown phases of all of the landings were taken from the ground.

Approach Pattern Calculations

The range of practical approach trajectories for any given airplane can be readily computed if appropriate lift and drag data are available (ref. 4). The values assumed for the test airplane are shown in figure 2. No attempt was made to include in these values allowances for residual engine thrust, or to assess the validity of the data in regard to their application to the specific test airplane. It was felt that any discrepancies that appeared as a result of errors in these data would be discovered in initial flight tests, would be systematic in nature, and would require but minor adjustment of the approach pattern.

Since only the desired end conditions of landing speed and touchdown point are known, determination of a pattern involves a step-by-step calculation of speed and position, backwards in time, along the 3° flight path of phase III, and through phase II to a suitable glide angle and speed defining phase I. Flight-path computation methods used for these tests are presented in the appendix. The computed variation of speed with distance from touchdown for the test airplane along the 3° flight path of phase III is shown in figure 3. Determination of the flight path of the pull-out, phase II, depends upon several considerations. The final velocity of this maneuver is specified by the desired length of phase III. In order to maintain the maximum precision in the execution of the pattern, it appears desirable to execute the phase II maneuver as quickly as possible while maintaining a safe margin of available lift for emergency maneuvering. For the test airplane, a lift coefficient of 0.4 was chosen as maximum for the phase II maneuver. For ease of computation, the rate of change of flight-path angle, as defined by the chosen lift coefficient and the velocity at the end of phase II, V_{III}, was held constant for the calculation of each phase II trajectory. For the conditions of the tests, a constant value of rate of change of flight-path angle corresponds to an approximately constant value of normal acceleration, which provides a convenient and familiar command for the pilot. The required terminal conditions in phase I were determined by finding, in the calculated phase II trajectory, the combination of speed and flight-path angle that corresponds to a steady-glide condition. The method used to accomplish this is illustrated in figure 4. The variation of speed with flight-path angle is shown for four phase II flight paths corresponding to various values of V_{III}. The variation of glide angle with speed in unaccelerated flight is also shown on figure 4. The intersections of these curves define the required conditions in phase I. However, the requirements were modified for the actual tests in order that the pilot might have limited use of his speed brakes to cope with errors in his initial glide angle and a second steady-glide curve, representing a speed 25 knots faster than the stabilized speed with brakes fully extended, was used to program the conditions of phase I.

It can be seen that the information contained in figure 4 essentially defines the range of approach patterns available for the test configuration. The construction of such a plot is a logical first step when the application of this landing-approach technique to a particular airplane configuration is considered.

The data of figures 3 and 4, together with the distances and altitudes calculated therefrom, were used to derive the information shown in figure 5, which defines a family of approach paths for the test airplane. Figure 6 is a sketch of the pattern considered best adapted to the characteristics of the test airplane and to the objectives of the investigation.

An approach pattern was also calculated for the airplane with the landing gear, take-off flaps, and brakes extended throughout the approach trajectory. The maximum lift-drag ratio for this condition is about 2.8. The results of computations for phase II of this pattern are shown in figure 7. An artificial restriction to the pattern resulted from the gear-down limit speed of 300 knots. In order to maintain phase III as long as possible, while reducing the speed of phase I to 300 knots, it was necessary to reduce wing loading from 85 to 75 pounds per square foot, to vary the level of acceleration through the pull-out, and to increase the maximum C_L used in phase II from 0.4 to 0.6. In this case, phase II was completed to an altitude of 200 feet at a distance 5000 feet short of the touchdown point. Even without the gear-down speed restriction, the limited speeds available in phase I, together with the increased deceleration in phases II and III at this low lift-drag ratio, severely limit the dimensions of the pattern in comparison with the patterns computed for the configuration previously discussed.

A detailed discussion of the effects of deviations from the programmed flight pattern on the landing conditions is not considered necessary here, as they vary with the particular pattern and are readily estimated. It might be pointed out that, for the pattern of figure 6, the touchdown point would be displaced 65 feet for each knot of wind velocity at the altitudes of phases II and III. An error in airspeed of 10 knots at the beginning of phase II would displace the touchdown point 1000 feet.

Pilot Technique

The information provided the pilot for the landings performed in the tests is shown in figure 8. The selected touchdown point was located 2000 feet beyond the threshold of the runway which was 8000 feet in length. In the preflight briefings, the desired phase I aiming point was located on the photograph of the terrain. At the test site, points along the approach path were easily identifiable as the result of a well-defined agricultural pattern. The pilot then noted the corresponding values of phase I flight-path angle and speed, the programmed pull-out altitude, and the level of acceleration required in phase II.

Phase I was entered from an indicated speed corresponding to the maximum lift-drag ratio (about 240 knots) at altitudes between 15,000 and 25,000 feet. A push-over was initiated when it was estimated that the line of sight to the aiming point coincided with the desired flight-path angle. The attitude gyro instrument in the cockpit was used as a rough check that the resultant flight-path angle was satisfactory. The pilot then allowed the indicated airspeed to increase to that desired at the pull-out, retracting his speed brakes momentarily, if necessary. The pilot did not attempt to hold a precise level of normal acceleration during phase II; he tended to pull up to somewhat over the required g level and then to reduce his acceleration gradually as his flight path became directed toward the touchdown point. The flight path of phase III, as flown in these tests, tended to vary somewhat from the straight-line path of the computations. The initial portions were flown at a steeper angle than programmed, with the pilot aiming at the runway threshold rather than the touchdown point. Thus, the last few thousand feet were flown at a very shallow angle, resulting in negligible rates of descent prior to touchdown.

RESULTS

Measured Data

The results of 28 idle-power landings with the test airplane are listed in table I. The runs are listed chronologically and include all of the approaches attempted. The narrow range of touchdown speeds, 178-190 knots, and the small dispersion in touchdown points are considered to demonstrate the accuracy of the technique. It can be noted that, except for one approach which was aborted because of pilot distraction with communications, and two very high-speed approaches for which the programmed patterns were in error, the approaches were successful. These approaches resulted in touchdown points within 600 feet of that used in calculating the approach pattern, except for one landing in which the pilot overshot the landing point by 1600 feet. The recorded data do not disclose the reason for the full magnitude of this error; however, the wing loading during this run was higher than the average, and speed and altitude were both higher than specified at the initiation of phase II.

As one might expect after observation of the geometry of the approach pattern, errors in the initial flight-path angle γ_I do not seriously influence the remainder of the maneuver if the speed at the start of phase II is correct, and if the pilot adjusts the normal acceleration during phase II to bring the airplane to the 3° path of phase III. The geometry of two typical approaches compared with the calculated pattern is shown in figure 9.

Pilots' Comments

The impressions of the power-off approach technique, reported by the two pilots involved in the tests, have been uniformly favorable. In the tests, it was necessary for the pilots to estimate the initial glide angle, but this was not a critical judgment in view of the speed control which was available to them. During the conception of the maneuver, some reservations were felt regarding the pilots' attitudes toward maintaining steep glide angles at speeds in excess of 400 knots, to an altitude of 2000 feet. The pilots reported that performing the maneuver once at higher altitude dispelled any apprehension they might have had regarding their ability to perform the pull-out safely.

The long final approach, with no maneuvering or speed control required, allowed more than adequate time for a landing check-list to be completed. Apparently because of the speed margin programmed for the vicinity of the runway threshold, together with the rapid deceleration, the pilots felt little concern regarding the possibility of seriously undershooting or overshooting the touchdown point. The pilots felt, and the data show, they were as precise in their execution of their first approaches as they were in subsequent landings. This would support the contention that the technique does not depend to any great degree on learning or judgment.

Subsequent to the tests, other pilots representing the Air Defense Command, the Air Force Flight Test Center, and the Flight Research Center of the NASA were invited to fly the test airplane in evaluation of the technique. Each of three pilots performed at least five power-off approaches, demonstrating the same precision as was shown in the initial tests. No practice flights were made, and a minimum of preflight briefing was found to be necessary. The pilots' impressions were generally similar to those of the Ames pilots.

DISCUSSION

The experience to date with the technique has been very encouraging, but in the course of the calculations and the tests there appeared indications that application of the procedure to aircraft of widely differing aerodynamic characteristics should be made with caution. The landing approaches performed with the test airplane with gear and flaps extended throughout the approach illustrate the restrictions to the pattern resulting from very low values of maximum lift-drag ratio. If the lift-drag ratio were decreased, a point would eventually be reached where landing the aircraft would be physically impossible, because the airplane would not have enough energy at the end of phase I to complete the pull-out to a path parallel with the ground. This limitation, when a variety of airplane configurations is considered, would be a function of drag due to lift, maximum lift, and minimum drag - not of maximum lift-drag ratio alone. On the other hand, preliminary calculations and a minimum of exploratory flight experience indicate that the proposed landing pattern is more difficult to fly with aircraft of higher maximum lift-drag ratios, such as the F-100C and T-33. Due to the lower rate of speed reduction during phase III, it is necessary to demand closer adherence to the programmed flight pattern in order that the aircraft arrive at the touchdown point within the desired speed range. It appears that the proposed landing-approach pattern can be flown most easily with an aircraft that is capable of changing from a moderate drag configuration in phase I to a high drag configuration early in phase III.

The technique appears to be particularly suitable for airplane configurations having the maximum value of lift-drag ratio at speeds considerably above the stalling speed or minimum-control speed. With standard landing techniques, either power-on or power-off, it is desirable to keep the approach speed as low as possible with respect to the touchdown speed, in order to increase the precision with which the desired touchdown point and speed can be attained. However, to provide maximum speed and flight-path control during the early stages of the approach, it is desirable, if not necessary, to fly at speeds well above that for maximum lift-drag ratio, where the normal relationship of steepening glide angle with increasing speed exists. From figure 10, in which is shown glide angle versus speed for a hypothetical configuration based on the test airplane, it can be seen that in order to satisfy this latter requirement, the approach speed must be well above 240 knots. A solution to the resultant problem of judging the distance required to decelerate from these high approach speeds to the speed for touchdown is found in the rigidly programmed pattern associated with the technique proposed in this report. Operation at speeds below that for maximum lift-drag ratio, on the "back side" of the drag curve, if it is limited to the latter part of phase III, has no particular significance in the proposed pattern if longitudinal and lateral control remain adequate to maintain a straight-line flight path to the speed of touchdown. Within what appears to be a practical range of vehicle configurations, the deceleration along the flight path of phase III (an inverse function of the lift-drag ratio) in itself should not be disconcerting to the pilot since it is of a lower level than is routinely experienced in other flight maneuvers.

Also shown in figure 10 is the effectiveness of a speed brake as a control device for speed or flight path angle in a power-off landing pattern. The incremental drag coefficient of the brake of this hypothetical configuration is 0.04, the same as that of the speed brakes on the test airplane. For glide angles between 20° and 30°, speed modulation capabilities of the speed brake remain constant at about 100 knots. However, since the deceleration produced by the brake is proportional to dynamic pressure, the control power provided at the higher approach speeds inherent in the proposed technique facilitates much more precise speed control than would be available at normal approach speeds. When the speed brake is considered as a flight-path-angle control at a constant airspeed, it provides flight-path-angle modulation over a range of 18° at 400 knots, as compared with 5° at 240 knots.

CONCLUDING REMARKS

Measured data and pilot opinion indicate that the proposed approach technique is practical for power-off landings of aircraft having high wing loadings and low lift-drag ratios. The accuracy and consistency of the approaches demonstrated with the test airplane indicate that the individual tasks presented by this technique are compatible with the average pilot's normal flying experience, and that the successful use of the technique is relatively independent of practice. Because of the reduced number of variables requiring pilot judgment, the landing capabilities of vehicles, when this technique is used, depend more on aerodynamic limitations and less on pilot skill.

It appears that, for aircraft having lift-drag ratios higher than those of the test airplane, the proposed technique tends to lose some of the demonstrated advantages as a result of necessary compromises in the approach-pattern geometry. In such cases, it might be well to consider the feasibility of lowering the lift-drag ratio for the landing approach with a device, such as a drag parachute or additional speed brakes mounted on the landing gear.

Since it is limited to a single vertical plane, the approach pattern demonstrated in these tests is compatible with practical schemes of electronic guidance or automatic control incorporating either ground-based or on-board equipment. The resultant all-weather capability would be particularly valuable to a nonpowered re-entry vehicle.

The next desirable step in the development of this approach technique would be to determine procedures to be used in guiding a vehicle from extreme altitudes to the initial approach flight path. In contrast to conventional approach techniques, the altitude of entry into the proposed pattern is not specified, except that it be high enough to allow the aircraft to accelerate to the programmed value of the initial approach speed.

A
2
5
0

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., March 23, 1960

APPENDIX

APPROACH-PATTERN EQUATIONS

The following equations were used in the computation of the approach patterns for the test airplane. When applying them in the computations of flight paths for aircraft having considerably different aerodynamic characteristics than those of the test airplane, care should be taken that the simplifying assumptions inherent in the equations are not seriously violated. Additional definitions pertinent to these equations are

A250

a_{n_T} normal acceleration at termination of phase II, g units

g acceleration due to gravity, 32.2 ft/sec^2

v velocity, ft/sec

γ_r flight-path angle, radians

$\dot{\gamma}_r$ rate of change of γ_r with time, radians/sec

ρ atmospheric density, slugs/ft^3

PHASE III

The relationship of velocity to the distance from the touchdown point was computed by a step-by-step process using increments of velocity in which the value of L/D can be assumed constant. Letting v_o be the touchdown velocity, and $v_1, v_2, \ldots, v_n$, velocities at increasing distances from touchdown,

$$\Delta v = v_n - v_{n-1}$$

and the corresponding incremental distance

$$\Delta d = \frac{\Delta v \left(v_n - \frac{1}{2}\Delta v\right)}{\left(\frac{1}{L/D} - \gamma_{r_{III}}\right)g}$$

PHASE II

In order to simplify the equations for the phase II maneuver, γ_{III} is considered to be zero. The effects of this assumption are readily computed. The equations were derived for a condition of constant rate of change of flight-path angle, which is determined from the relationship

$$\dot{\gamma}_r = \frac{(a_{n_T} - 1)g}{v_{III}}$$

If L/D is assumed to remain constant over the speed range of the maneuver, the relationship of velocity to flight-path angle is

$$v = v_{III}\left[\frac{a_{n_T}\gamma_r}{\frac{L}{D}(a_{n_T} - 1)} + \frac{(\cos\gamma_r - 1)}{a_{n_T} - 1} + 1\right]$$

A 2 5 0

The corresponding values of height above and horizontal distance from the initial point of phase III are

$$\Delta h = \frac{{v_{III}}^2}{(a_{n_T}-1)^2 g}\left[\frac{a_{n_T}}{L/D}(\sin\gamma_r - \gamma_r\cos\gamma_r) + (2-a_{n_T})(\cos\gamma_r - 1) + \frac{\sin^2\gamma_r}{2}\right]$$

and

$$\Delta d = \frac{{v_{III}}^2}{(a_{n_T}-1)^2 g}\left[\frac{a_{n_T}}{L/D}(\cos\gamma_r + \gamma_r\sin\gamma_r - 1) + (a_{n_T}-2)\sin\gamma_r + \frac{\sin 2\gamma_r}{4} + \frac{\gamma_r}{2}\right]$$

PHASE I

The variation of velocity with flight-path angle for power-off unaccelerated flight, as shown in figure 4, is computed using the value of atmospheric density at the altitude of entry into phase II. The resultant effects on the validity of the calculated values for the terminal conditions of phase III should be considered for cases of high wing loadings and steep phase I glide angles which cause rapid changes in the relationship of true airspeed to indicated airspeed. Equations relating flight-path angle to velocity are

$$\frac{L}{D} = \cot \gamma$$

and, taking the value of lift coefficient corresponding to the resultant value of L/D,

$$v = \sqrt{\frac{2(W/S)\cos \gamma}{\rho C_L}}$$

REFERENCES

1. Matranga, Gene J., and Armstrong, Neil A.: Approach and Landing Investigation at Lift-Drag Ratios of 2 to 4 Utilizing a Straight-Wing Fighter Airplane. NASA TM X-31, 1959.

2. Reeder, John P.: The Effect of Lift-Drag Ratio and Speed on the Ability to Position a Gliding Aircraft for a Landing on a 5,000-Foot Runway. NASA MEMO 3-12-59L, 1959.

3. Drinkwater, Fred J., III, and Cooper, George E.: A Flight Evaluation of the Factors Which Influence the Selection of Landing Speeds. NASA MEMO 10-6-58A, 1958.

4. von Doenhoff, Albert E., and Jones, George W., Jr.: An Analysis of the Power-Off Landing Maneuver in Terms of the Capabilities of the Pilot and the Aerodynamic Characteristics of the Airplane. NACA TN 2967, 1953.

TABLE I.- RESULTS OF IDLE-POWER LANDING APPROACHES WITH TEST AIRPLANE

Pilot	Flight	Run	d_P, ft	Programmed γ_I, deg	Programmed V_I, k	Programmed h_{II}, ft	Recorded γ_I, deg	Recorded V_I, k	Recorded h_{II}, ft	Touchdown V, k	Touchdown d, ft	Remarks
A	1	1	17500	25	415	1900	19	415	1800	190	0	
		2	↓	↓	↓	↓	21	450				Distracted by traffic
		3	↓	↓	↓	↓	19	415	1800	180	400	
		4	↓	↓	↓	↓				190	200	
		5	↓	↓	↓	↓				185	-300	
	2	1	5500	26	300	1300				185	600	High drag configuration
		2	5500	26	300	1300	20	292	1400	190	600	
	3	1	17500	25	415	1900	17	415	2000	190	0	
		2	10500	16	335	1400	15	328	1400	180	0	
		3	15500	22	395	1700	17	389	1600	190	600	
	4	1	19500	28	435	2200	25	433	2300	185	450	(1)
		2	19500	28	435	2200	24	438	2300	185	-500	
		3	15000	22	390	1700	18	384	1600	180	-300	
		4	15000	22	390	1700	20	384	1700	185	0	(1)
		5	12500	18	360	1500	16	350	1500	190	200	
		6	12500	18	360	1500	17	350	1500	185	500	(1)
	5	1	22000	33	470	2700	27	470	3200			Wave off - too fast
		2	24000	39	495	3200	25	490	3100			
		3	17500	25	415	1900	23	425	2100	185	1600	(1)
		4	5500	26	300	1300	27	305	1400	183	600	High drag configuration
		5	5500	26	300	1300	28	300	1400	185	200	
B	6	1	17500	25	415	1900					-200	
		2	↓	↓	↓	↓	23	415	2200	183	500	
		3	↓	↓	↓	↓	22	425	2000	185	600	
		4	↓	↓	↓	↓	24	415	2000	185	200	
	7	1	6000	26	300	1300	26	300	1400	183	-600	
		2	↓	↓	↓	↓	25	300	1400	180	-400	High drag configuration
		3	↓	↓	↓	↓	28	303	1400	178	-200	

[1]No actual touchdown performed; touchdown point and speed extrapolated from conditions at approach end of runway.

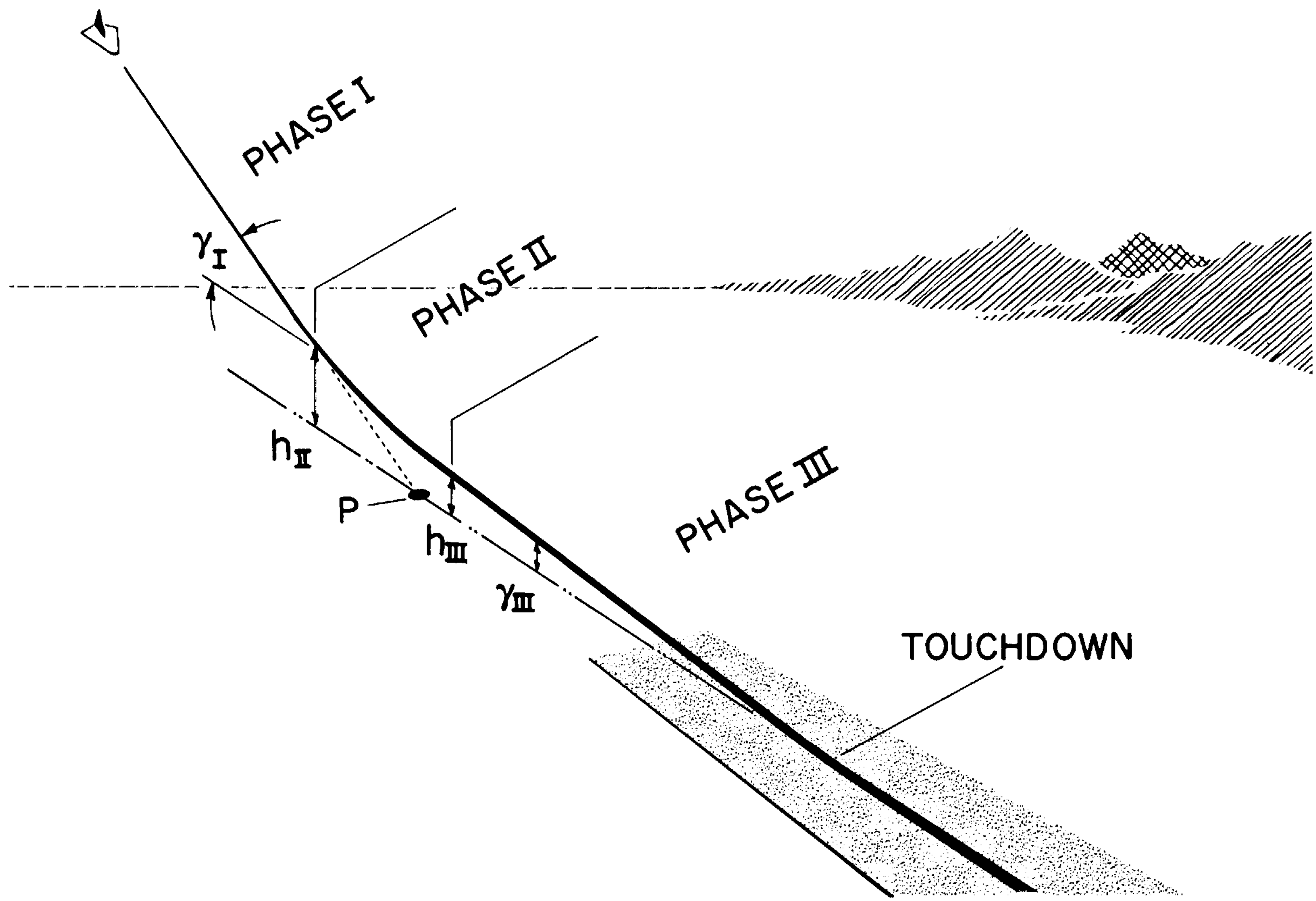


Figure 1.- Sketch of approach pattern.

3Y

A
2
5
0

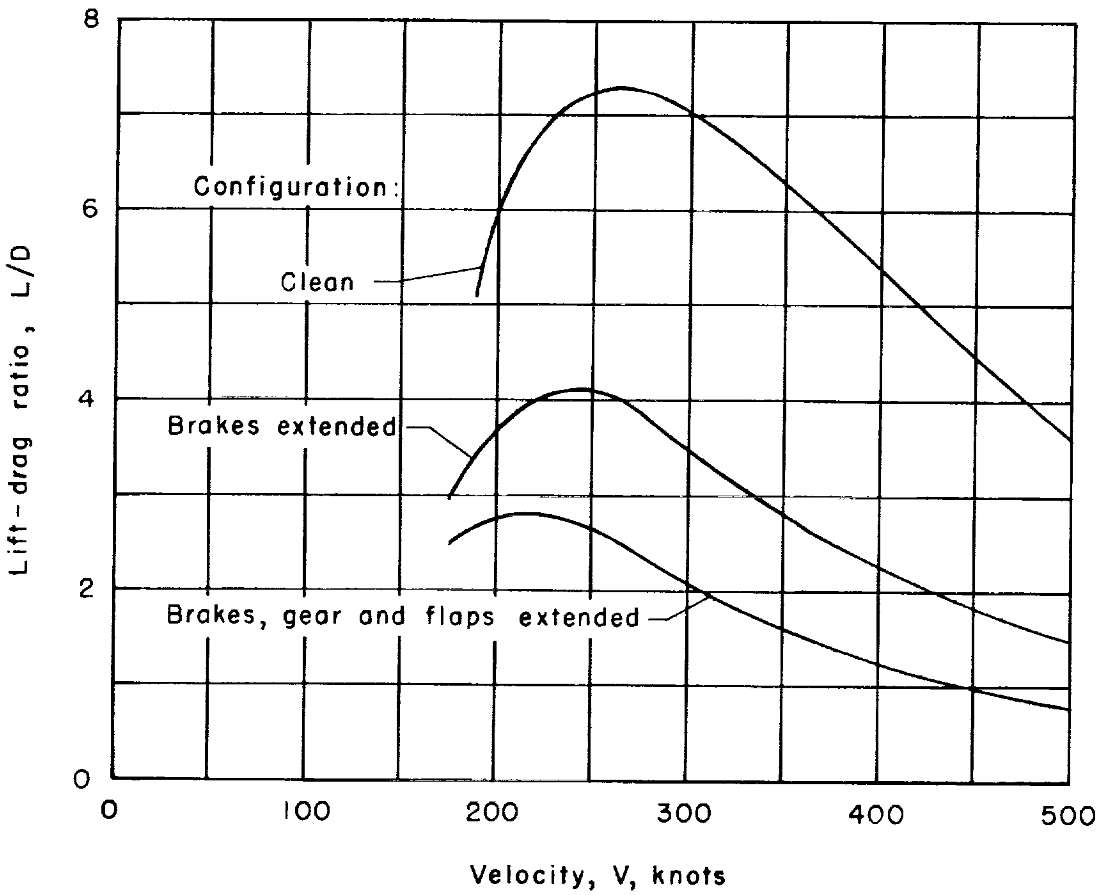


Figure 2.- Lift-drag ratios of the test airplane as a function of airspeed at an altitude of 1000 feet in level flight; W/S = 85.

A
2
5
0

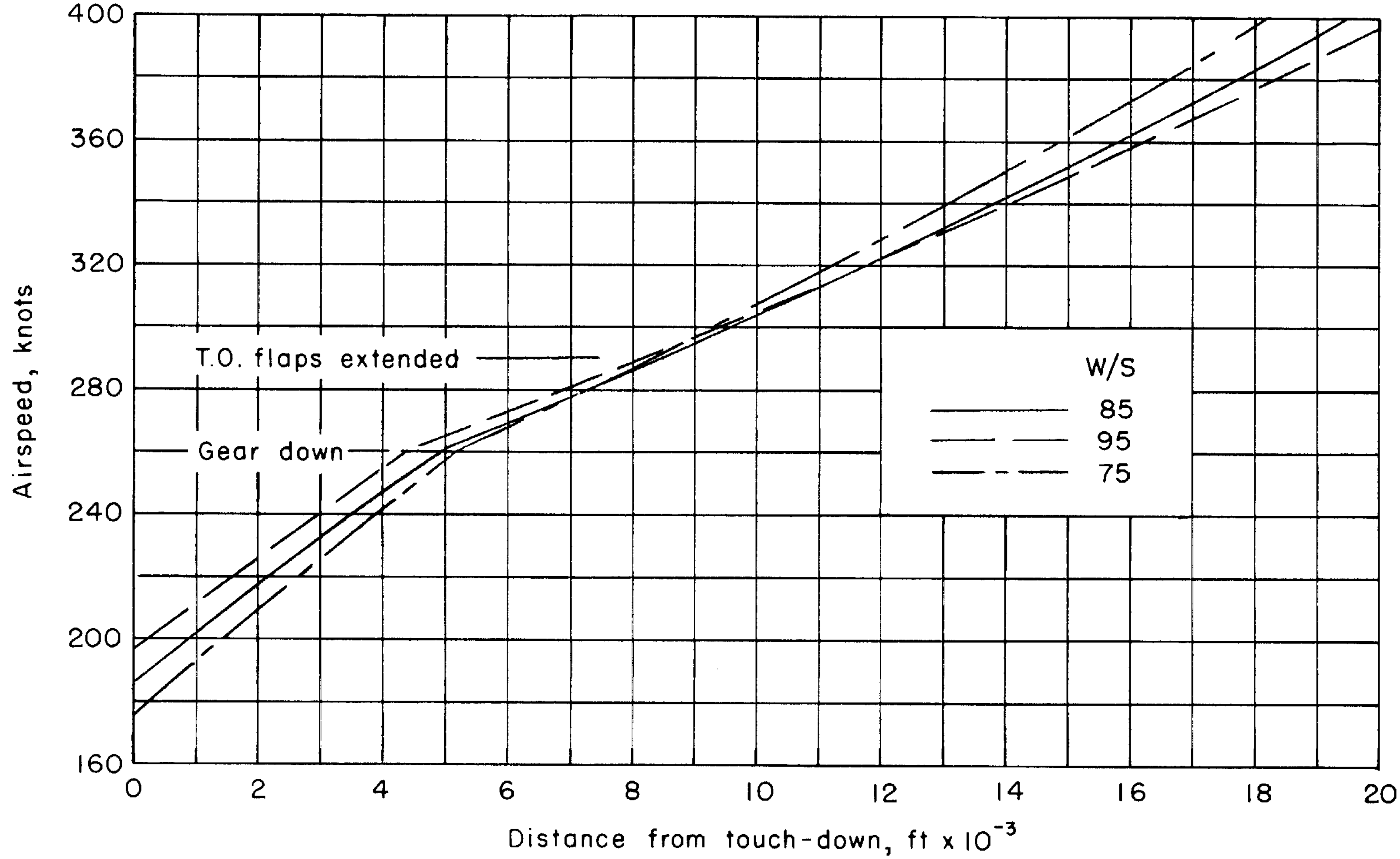


Figure 3.- Calculated variation of speed with distance from touchdown for test airplane on a 3^{o} approach path (phase III) at idle power, brakes out.

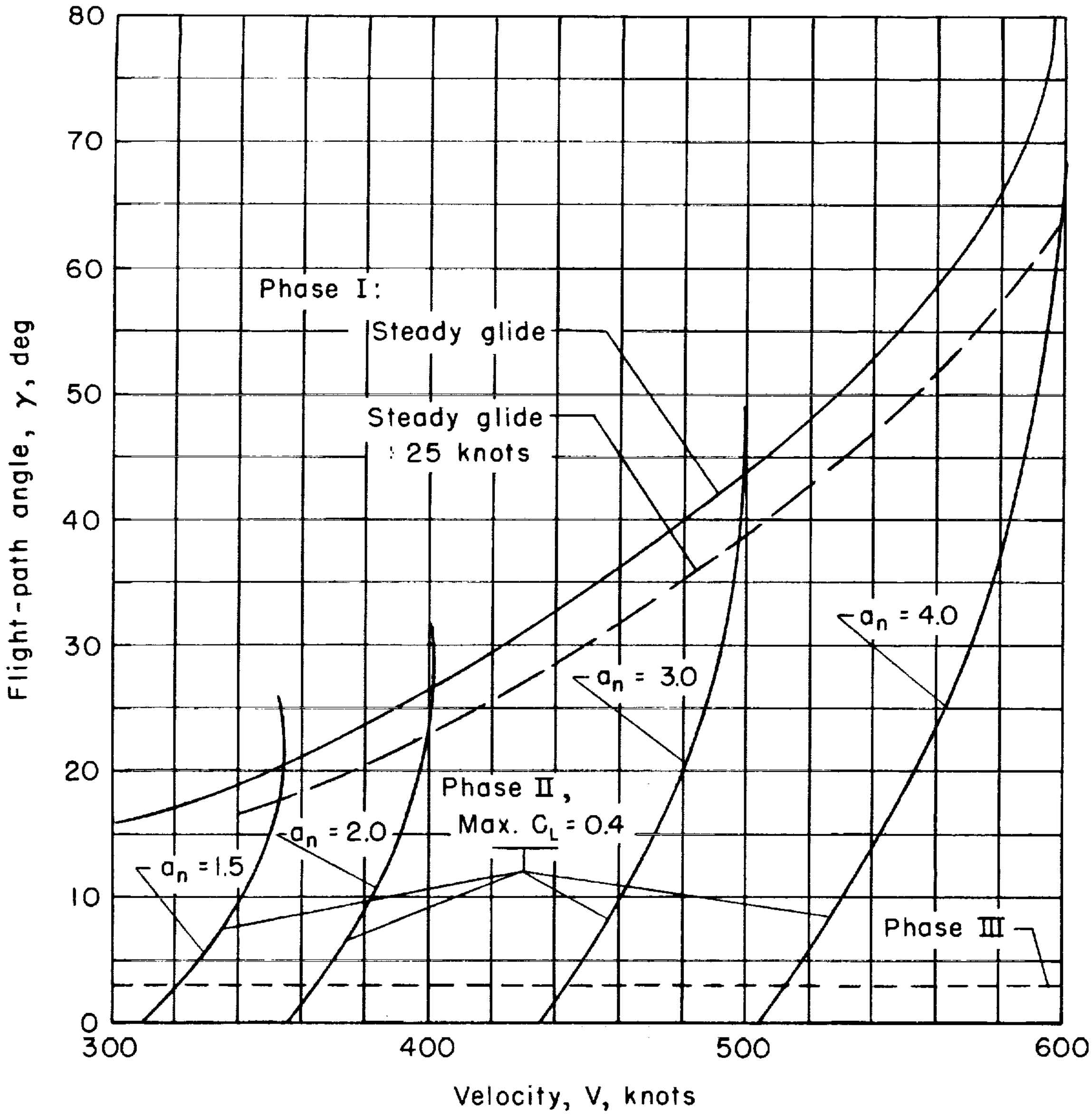


Figure 4.- Calculated variation of speed with flight-path angle for phases I and II; idle power, brakes out; W/S = 85.

A
2
5
0

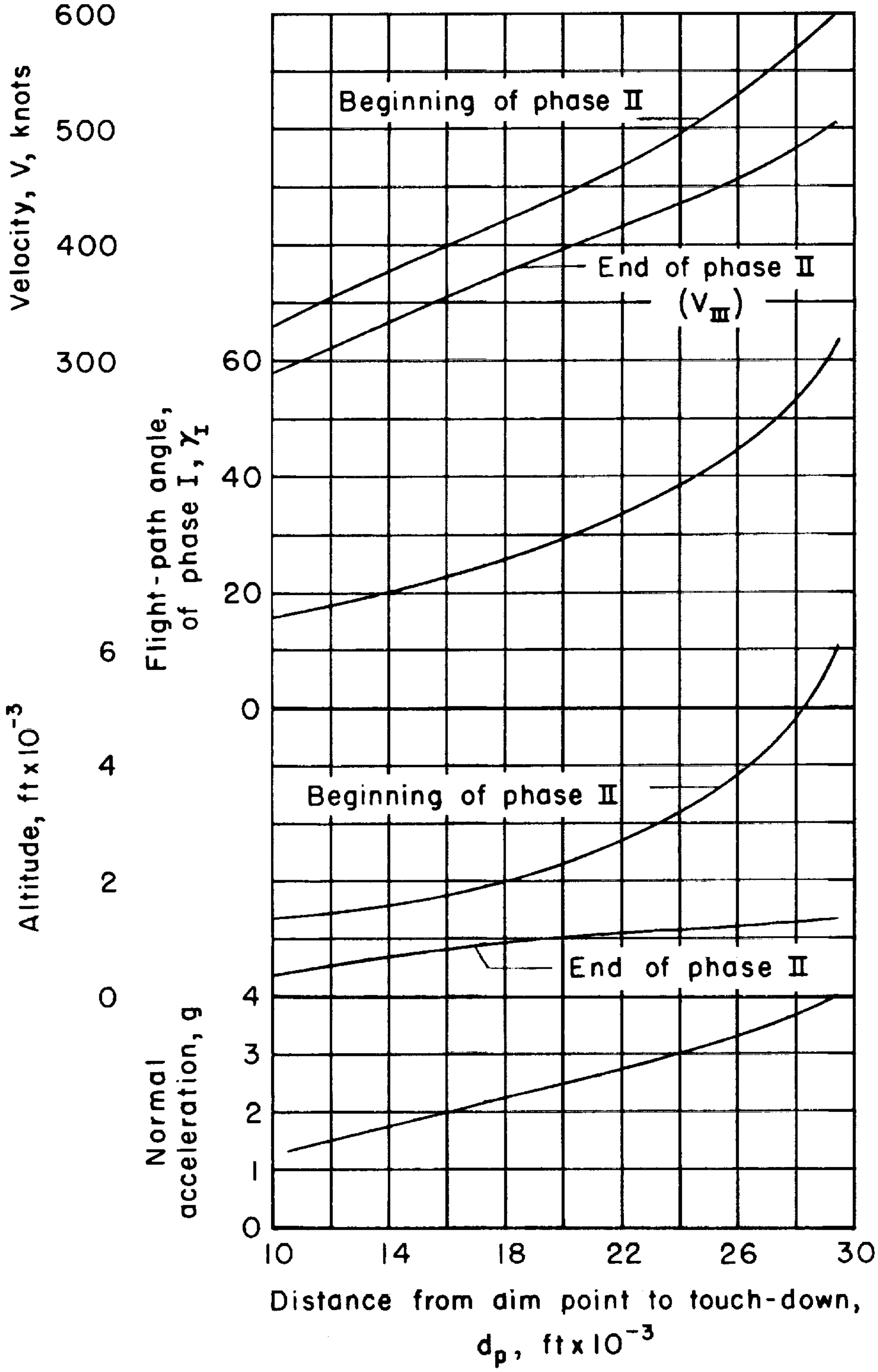


Figure 5.- Envelope of idle-power approach patterns for test airplane; brakes out, gear and flaps retracted; W/S = 85.

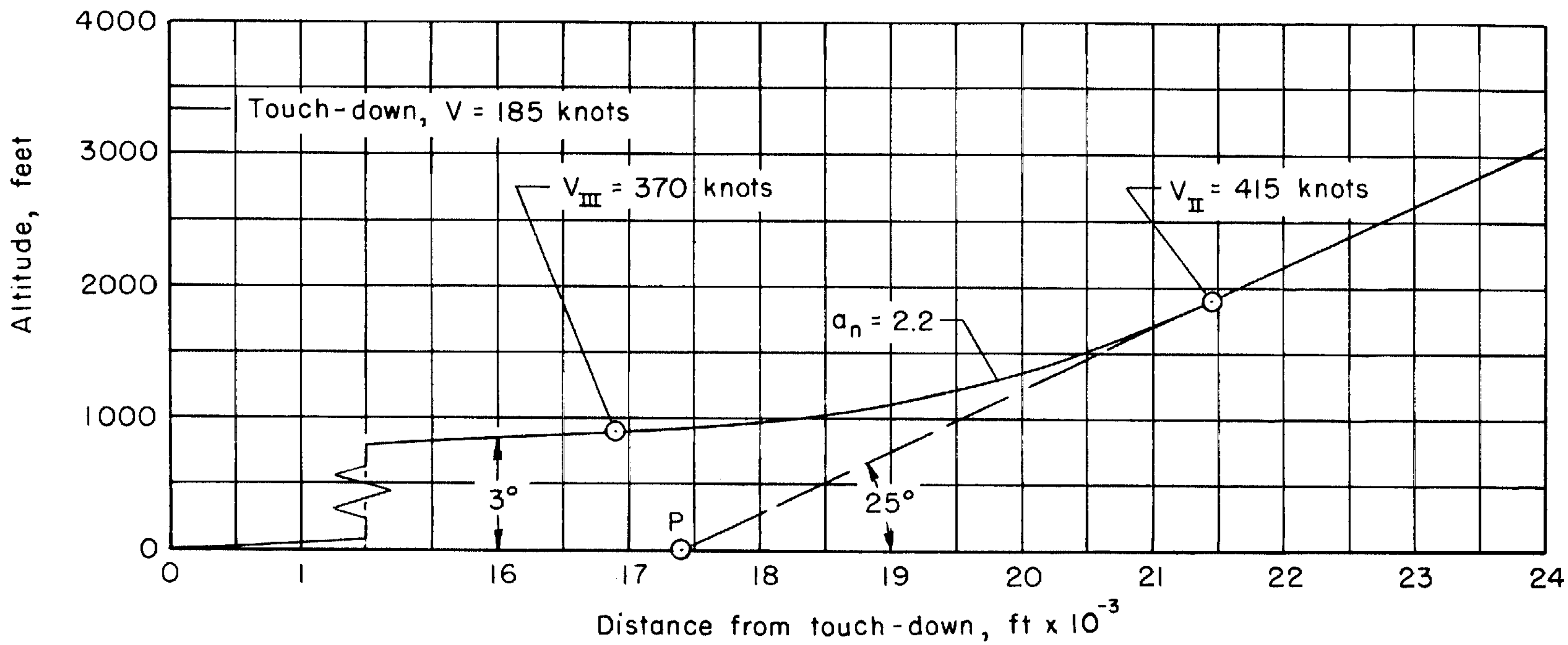


Figure 6.- Geometry of typical computed approach path.

A
2
5
0

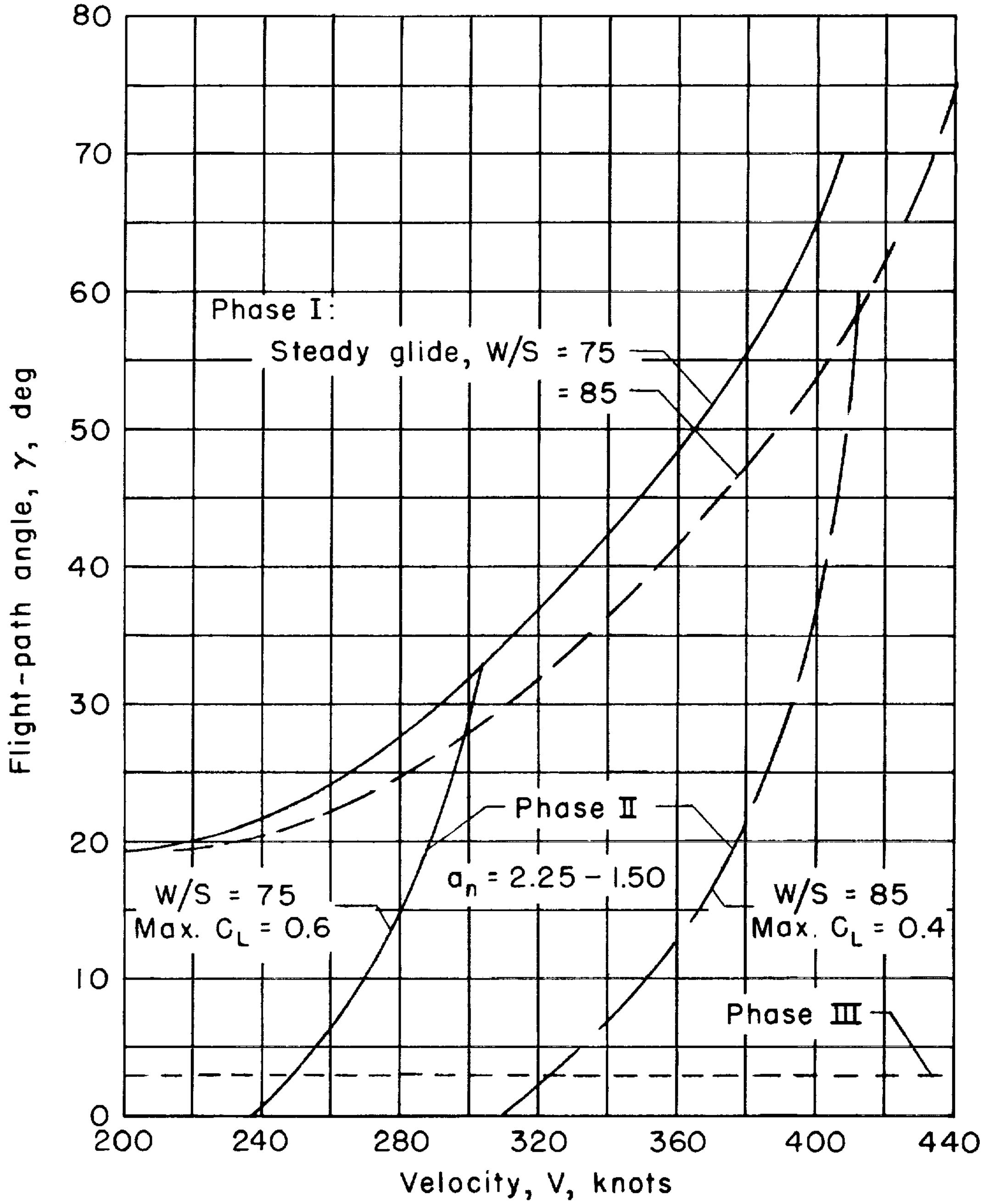
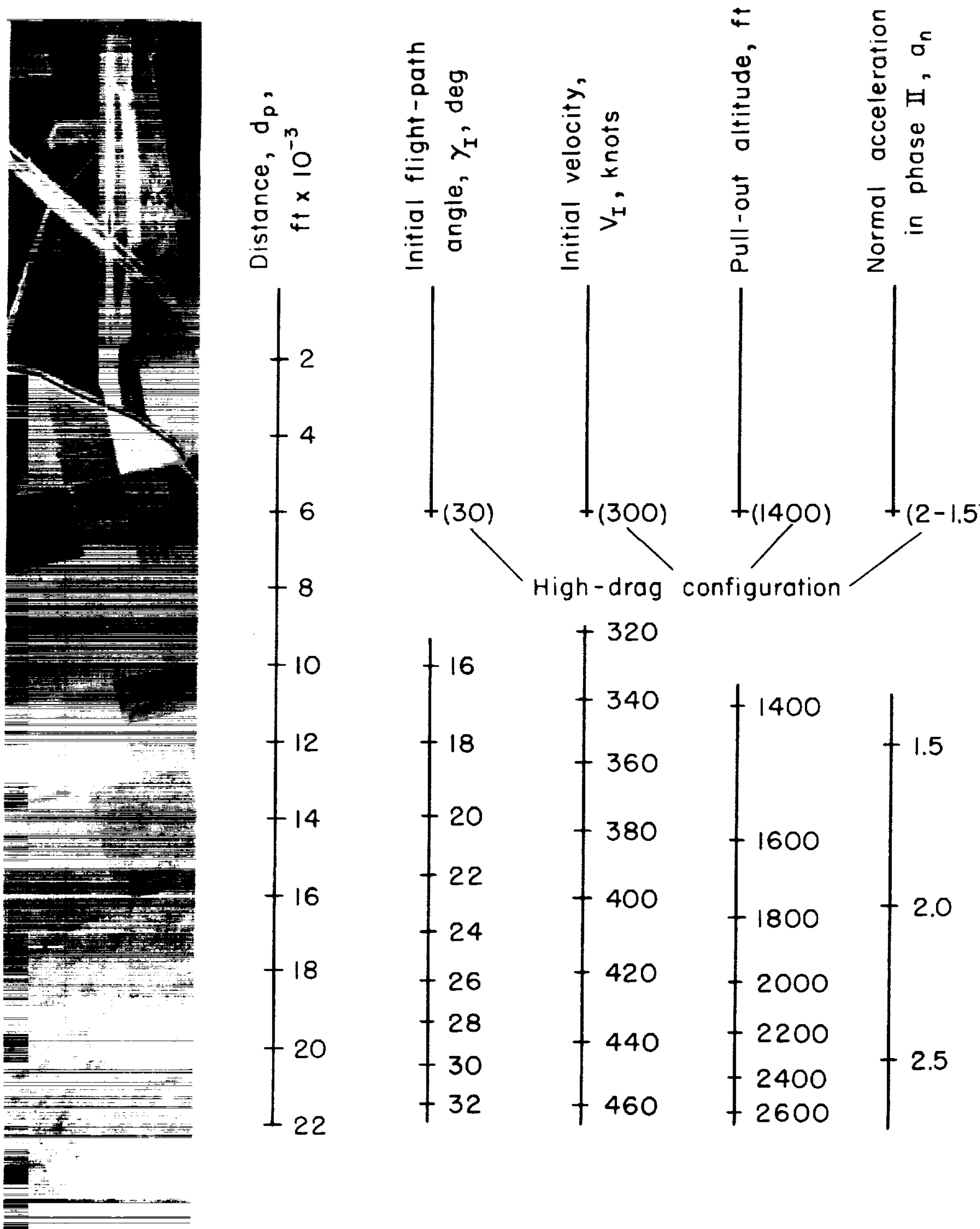


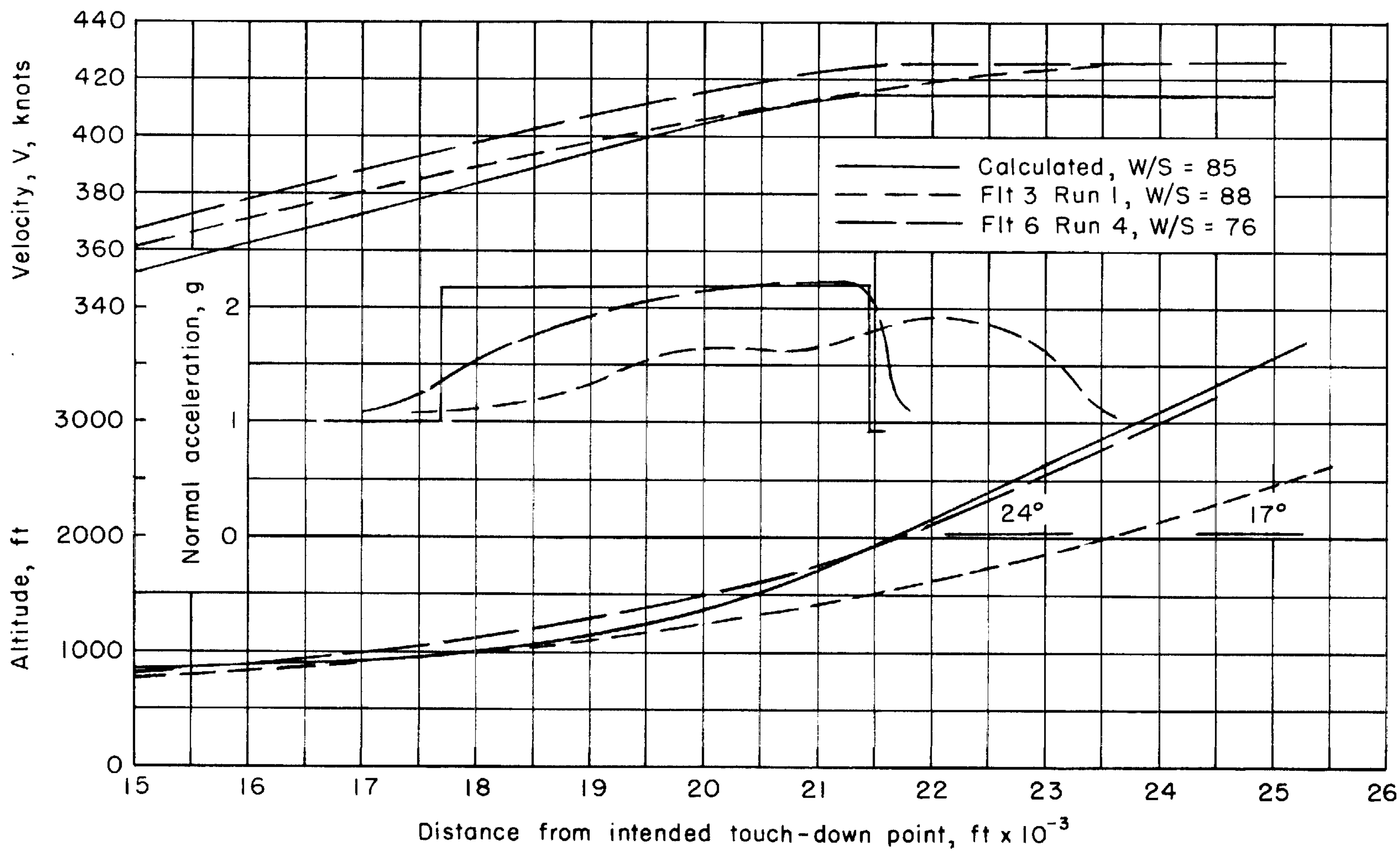
Figure 7.- Variation of speed with flight-path angle for test airplane in high-drag configuration; gear and take-off flaps down, speed brakes extended; $(L/D)_{max}$ = 2.8.



A
2
5
0

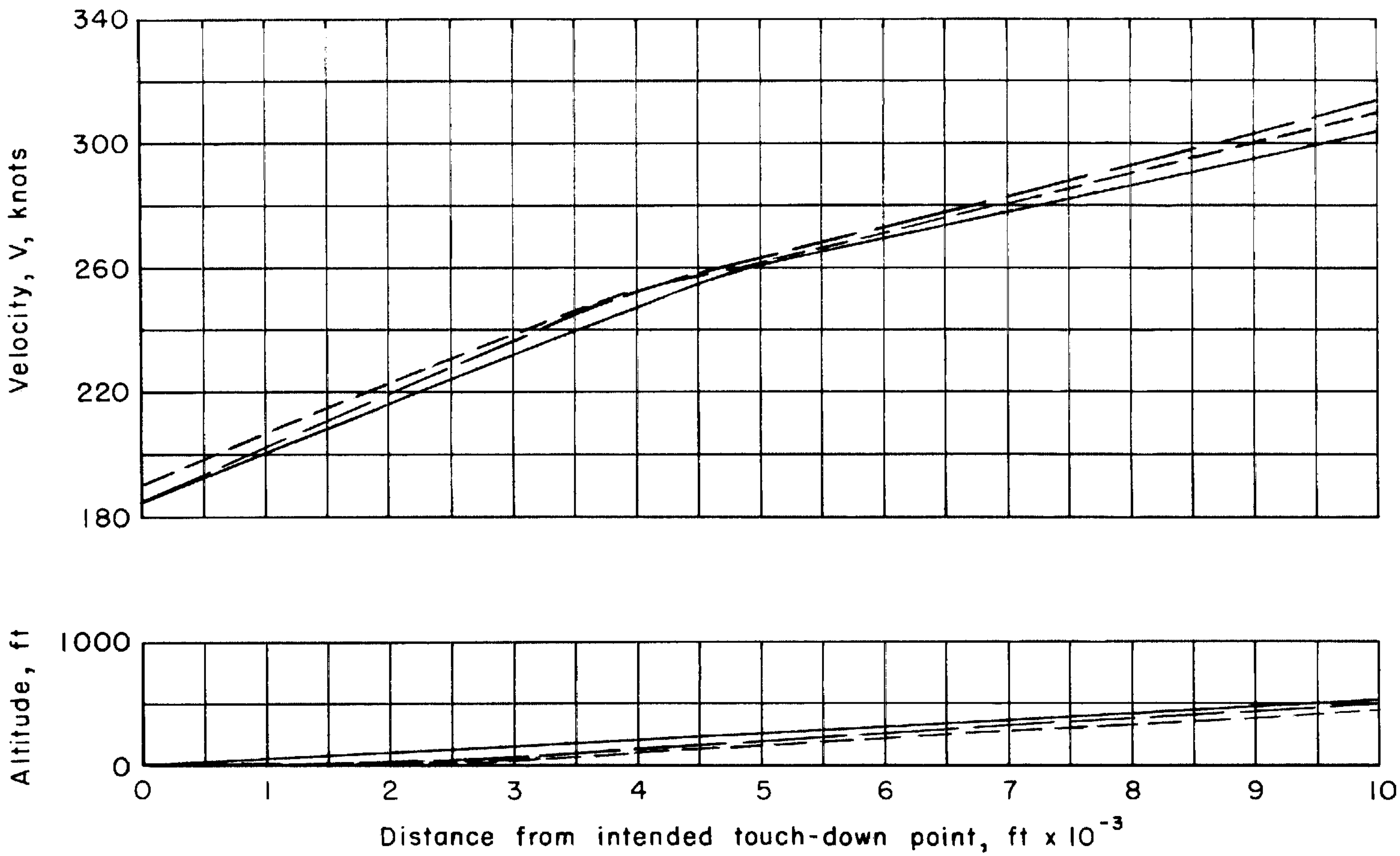
Figure 8.- Pilot's data sheet for idle-power landings with the test airplane.

A
2
5
0



(a) Phase II.

Figure 9.- Comparison of two typical idle-power approaches with the calculated flight path.



(b) Phase III.

Figure 9.- Concluded.

A-250

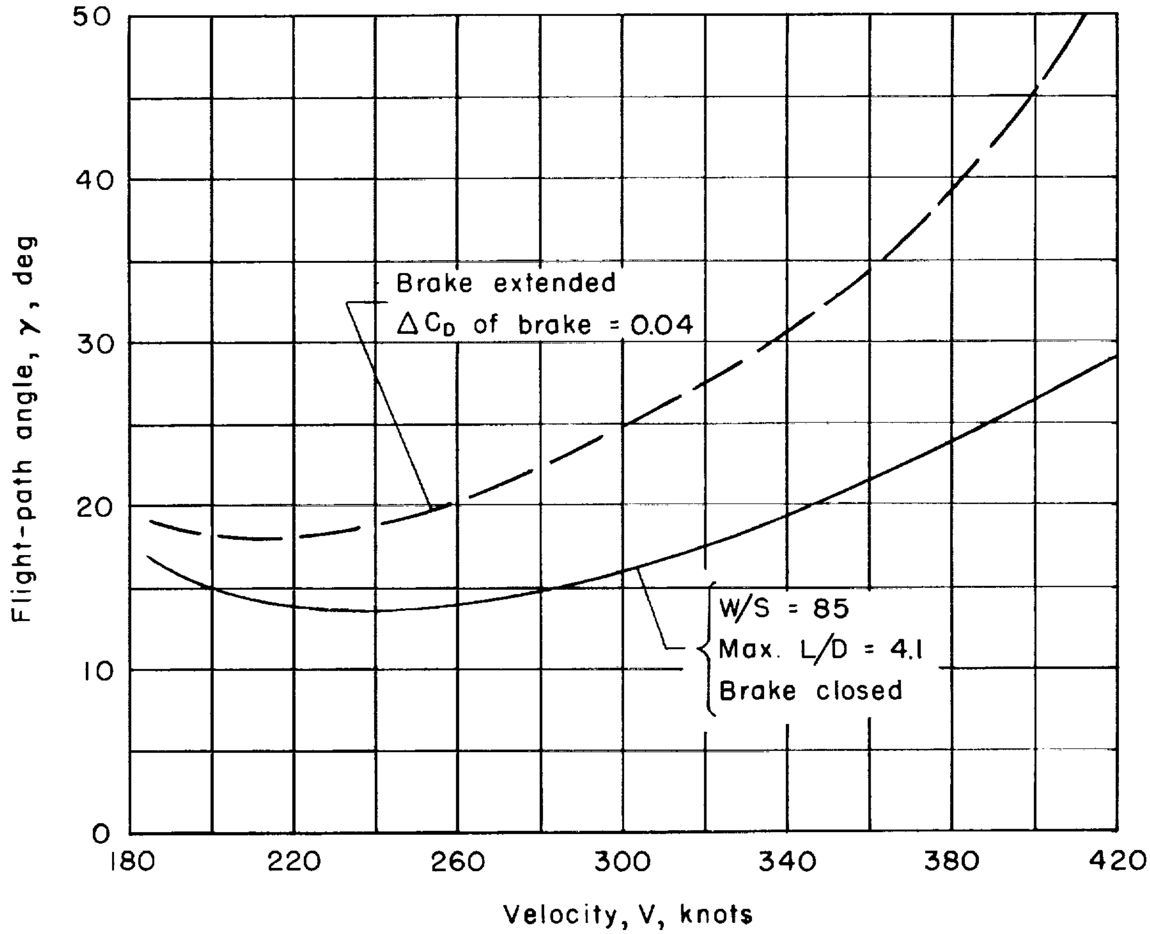


Figure 10.- Variation of glide angle with speed for hypothetical vehicle with speed brake closed and extended.